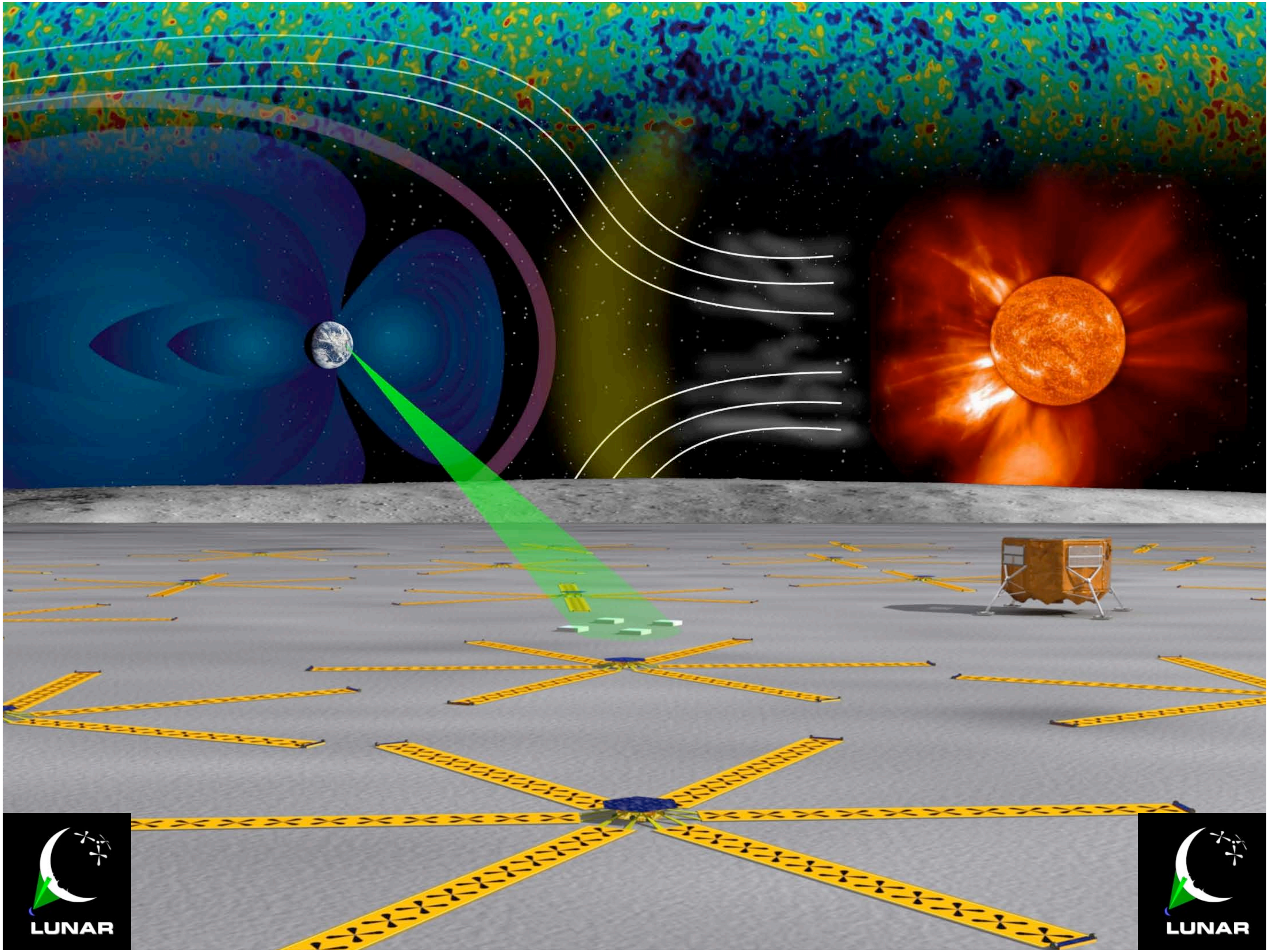
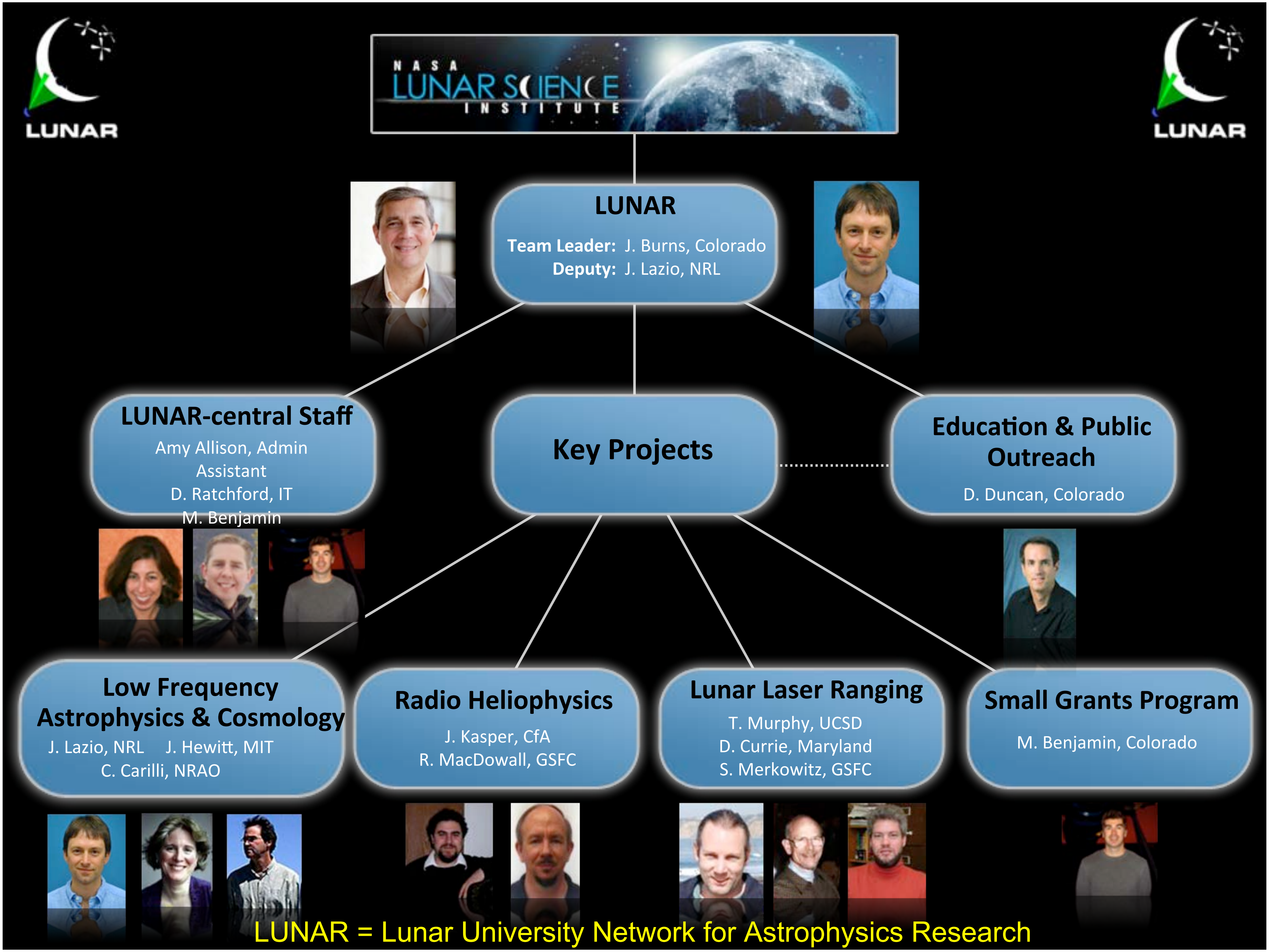
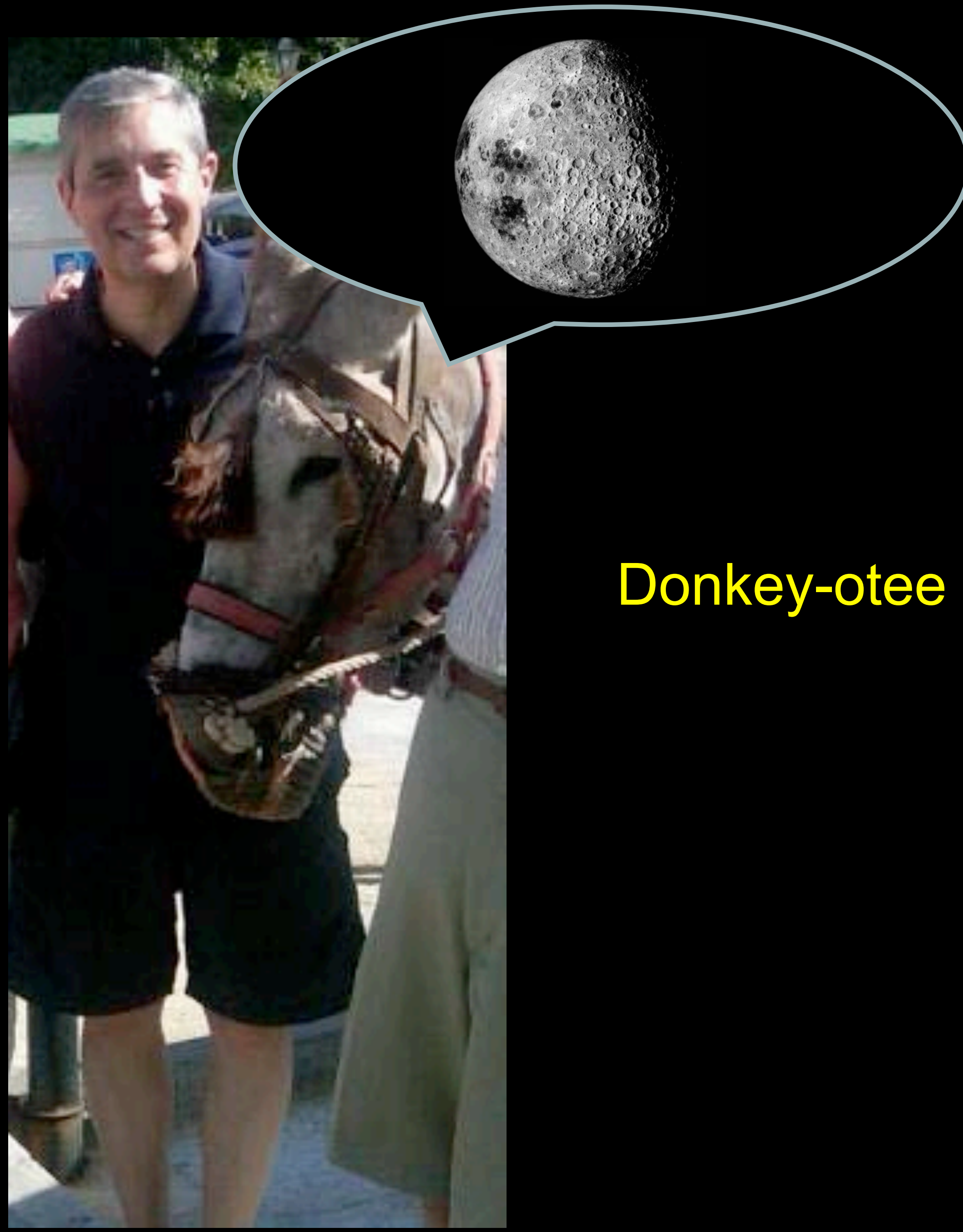
Low Frequency Astrophysics and Heliophysics from the Moon

Jack Burns and the NLSI LUNAR Team
University of Colorado at Boulder and NLSI

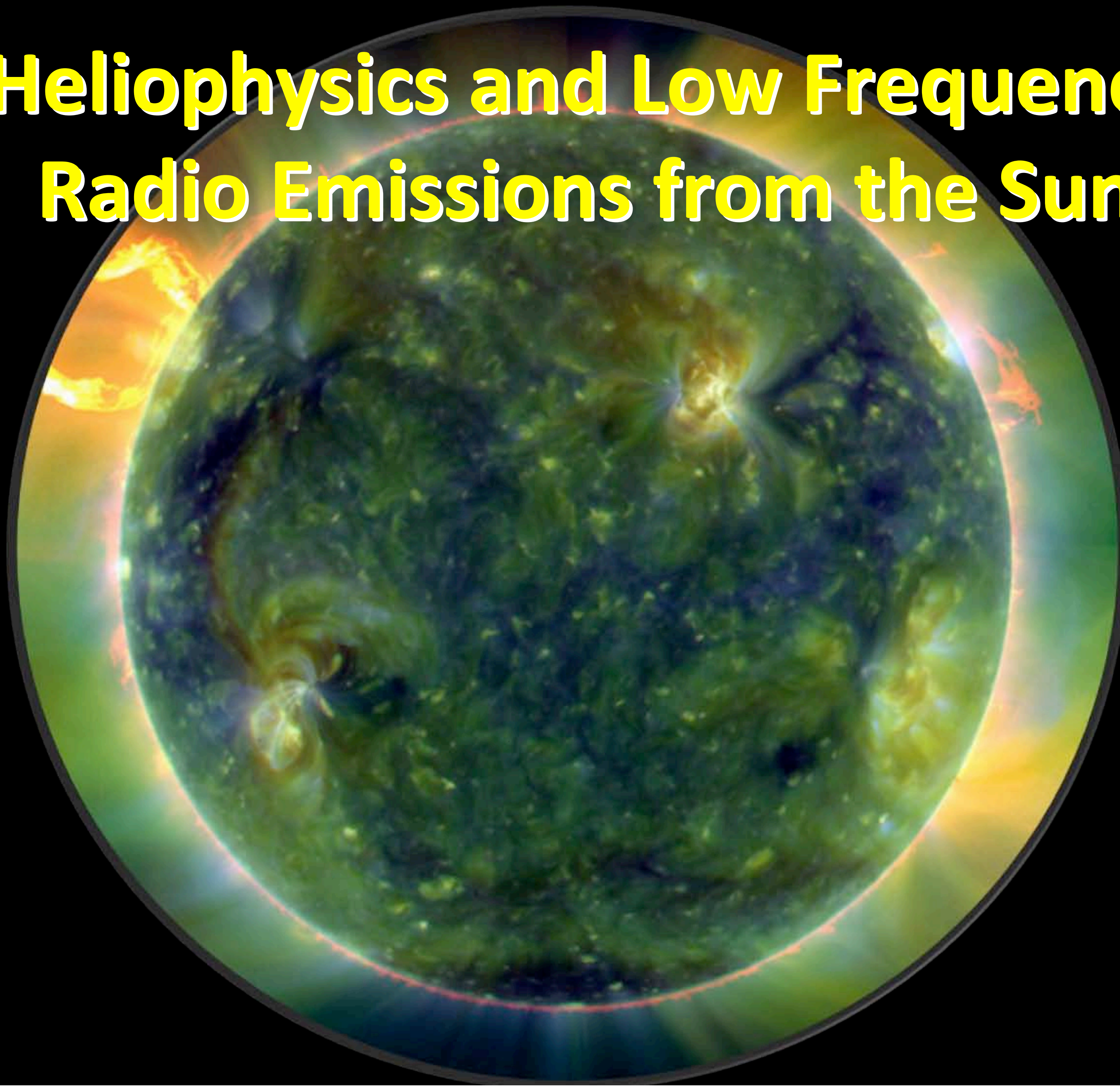

LUNAR
LUNAR


NASA LUNAR SCIENCE INSTITUTE
LUNAR
LUNAR
LUNAR
Team Leader: J. Burns, Colorado
Deputy: J. Lazio, NRL
LUNAR-central Staff
Amy Allison, Admin Assistant
D. Ratchford, IT
M. Benjamin
Key Projects
Education & Public Outreach
D. Duncan, Colorado
Low Frequency Astrophysics & Cosmology
J. Lazio, NRL J. Hewitt, MIT
C. Carilli, NRAO
Radio Heliophysics
J. Kasper, CfA
R. MacDowall, GSFC
Lunar Laser Ranging
T. Murphy, UCSD
D. Currie, Maryland
S. Merkowitz, GSFC
Small Grants Program
M. Benjamin, Colorado
LUNAR = Lunar University Network for Astrophysics Research



Donkey-otee

Heliophysics and Low Frequency Radio Emissions from the Sun



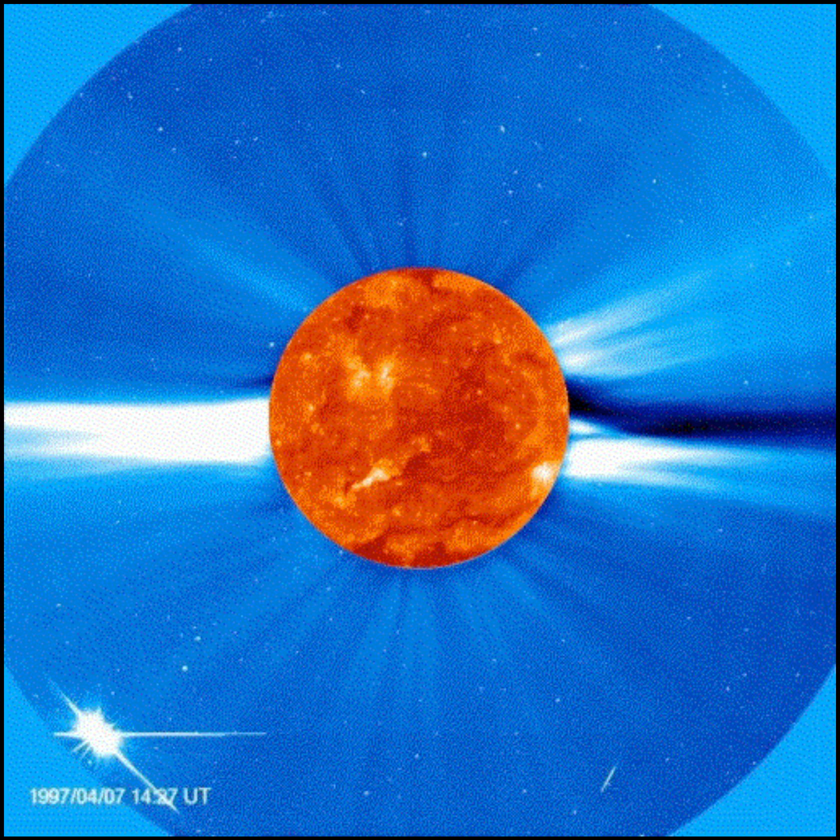
Radio Heliophysics from the Moon

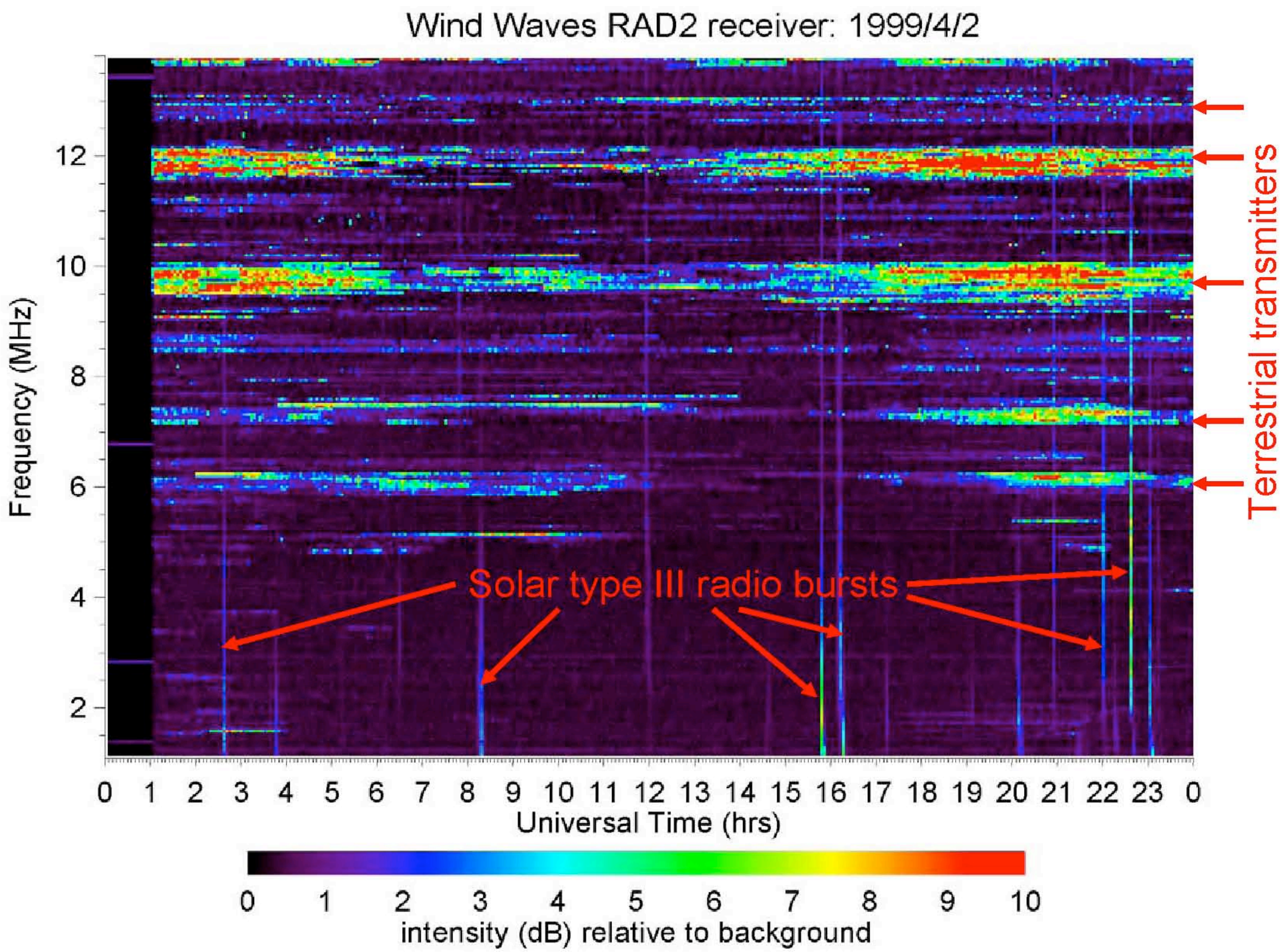
- How does high energy particle acceleration occur within the heliosphere?
- A low frequency lunar radio array will produce the first resolved ($\leq 2^{o}$ at 10 MHz), high time resolution images of solar radio emissions from the outer corona.

Coronal Mass Ejections

- Gas blown from Corona
  - 10^{15} grams of gas (lower limit average)
  - 10^{12} W of power.
- CMEs produce shock fronts where e^-, p^+, & ions are accelerated to 20 – 3000 km/s (keV – GeV) via Fermi process.

  => harmful to electronics, satellites, & astronauts in interplanetary space.
- Origin:
  - Correlation to solar flares, prominences & sunspot regions
  - Also occur in absence of the above
- CMEs often produce bursts of low frequency radio emission (Type II & III solar bursts).

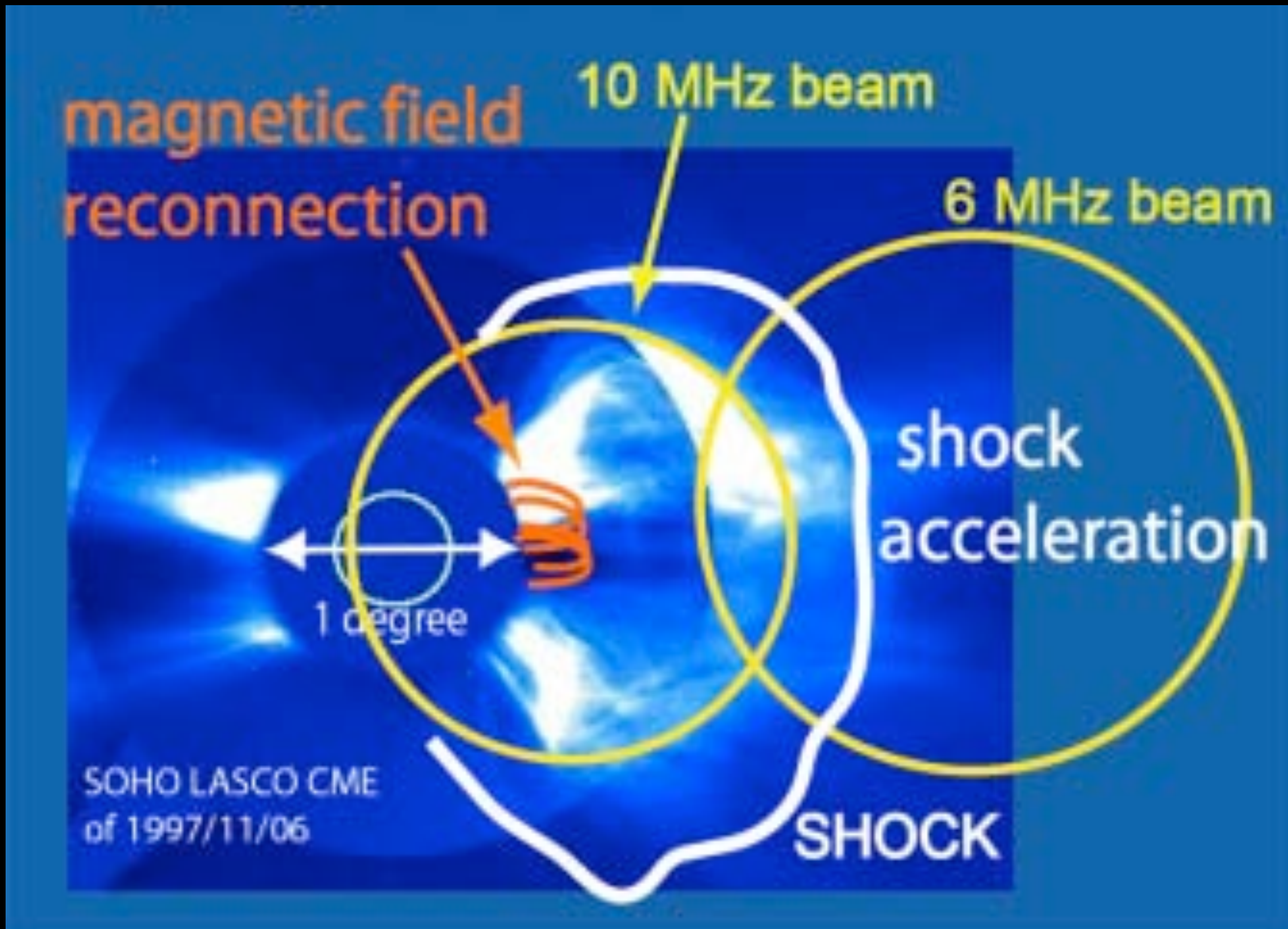




On 1999/4/2, the Wind spacecraft flew by the moon for a gravitational orbit maneuver. The Waves radio receiver observing in the 1-14 MHz range observed the emissions shown in the color-coded dynamic spectrum. The most intense emission are red in this plot. Several weak type III solar radio bursts are seen; they appear as vertical lines in the 24 hour duration plot because of their short duration. The horizontal bands are entirely ground-based radio transmissions, clearly showing the level of interference from human-made sources.

R. MacDowall *et al.*

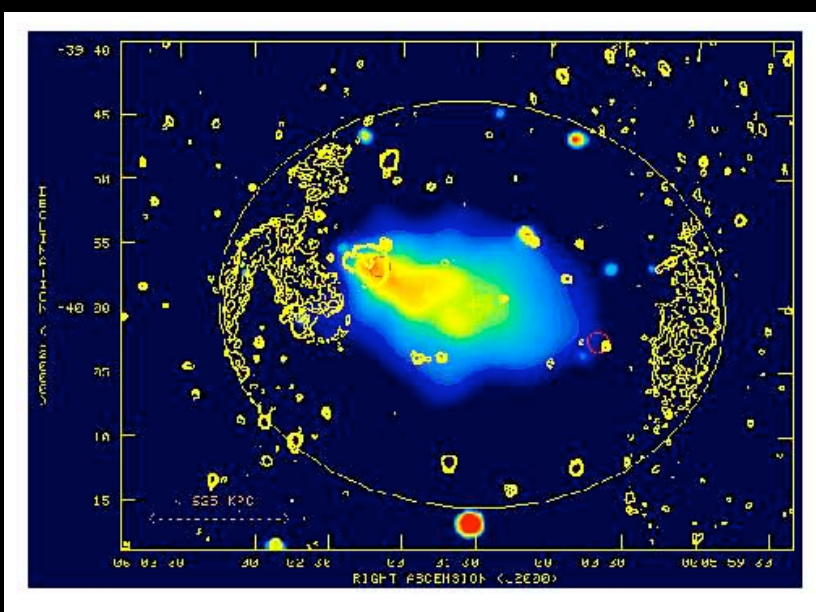
Imaging Solar Radio Bursts from a Lunar Array



Shock Acceleration also occurs commonly beyond solar system in e.g., Radio Galaxies

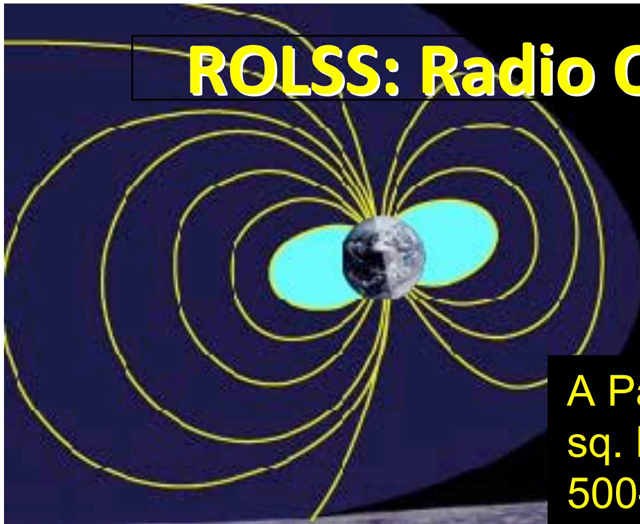
VLA radio (green) image superimposed on optical image of the nearby radio galaxy Centaurus-A (Clarke & Burns).

- For nearby, luminous radio galaxies such as Cen A, low frequency telescopes will detect or set limits on the minimum electron energy (E<50 MeV).
- Diffusive shock acceleration believed to fail for γ<2000, corresponding to υ=10 MHz for B=1 μG.



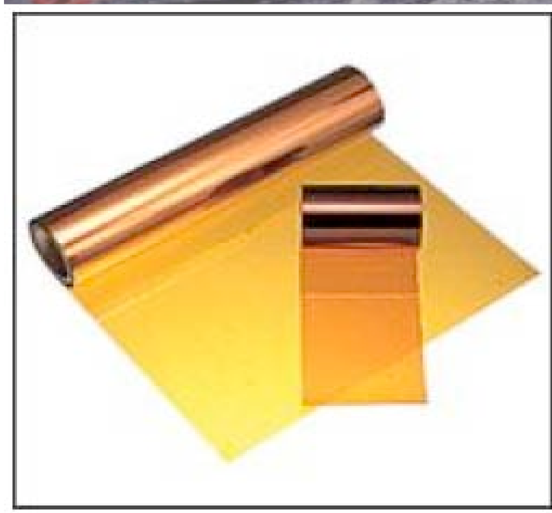
Radio & X-ray emission from Large-scale shocks in the merging galaxy cluster Abell 3376 (Bagchi et al. 2006).

ROLSS: Radio Observatory for Lunar Sortie Science



A Pathfinder for a future long-wavelength farside lunar array (10-100 sq. km). Operating at 1-10 MHz (30-300 m). Array consists of three 500-m long arms forming a Y; each arm has 16 antennas.

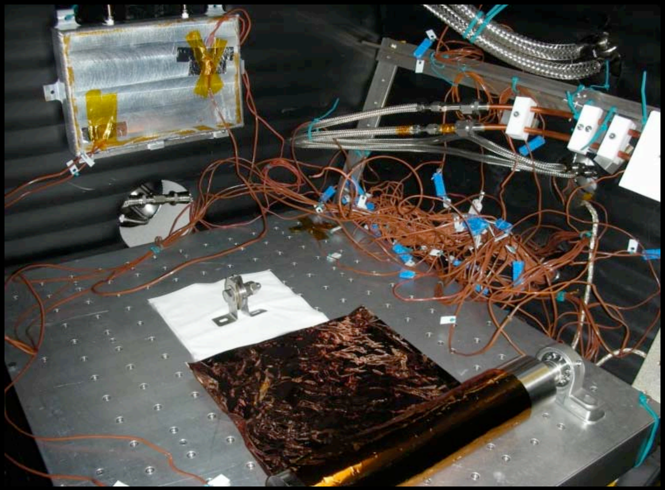
- Arms are thin polyimide film on which antennas & transmission lines are deposited.
- Arms are stored as 25-cm diameter x 1-m wide rolls (0.025 mm thickness).



See also posters #117, & talks by Lazio and Maruca in Session #2

LUNAR Kapton Testing

- The LUNAR team tested a sheet of copper plated Kapton film under vacuum for one month.
- Resistivity and tensile strength were measured to determine the reliability of the film over time.
- The film was cycled through day and night temperatures through contact with a thermally conductive plate. During daytime cycles, the film was bombarded with harsh UV radiation.

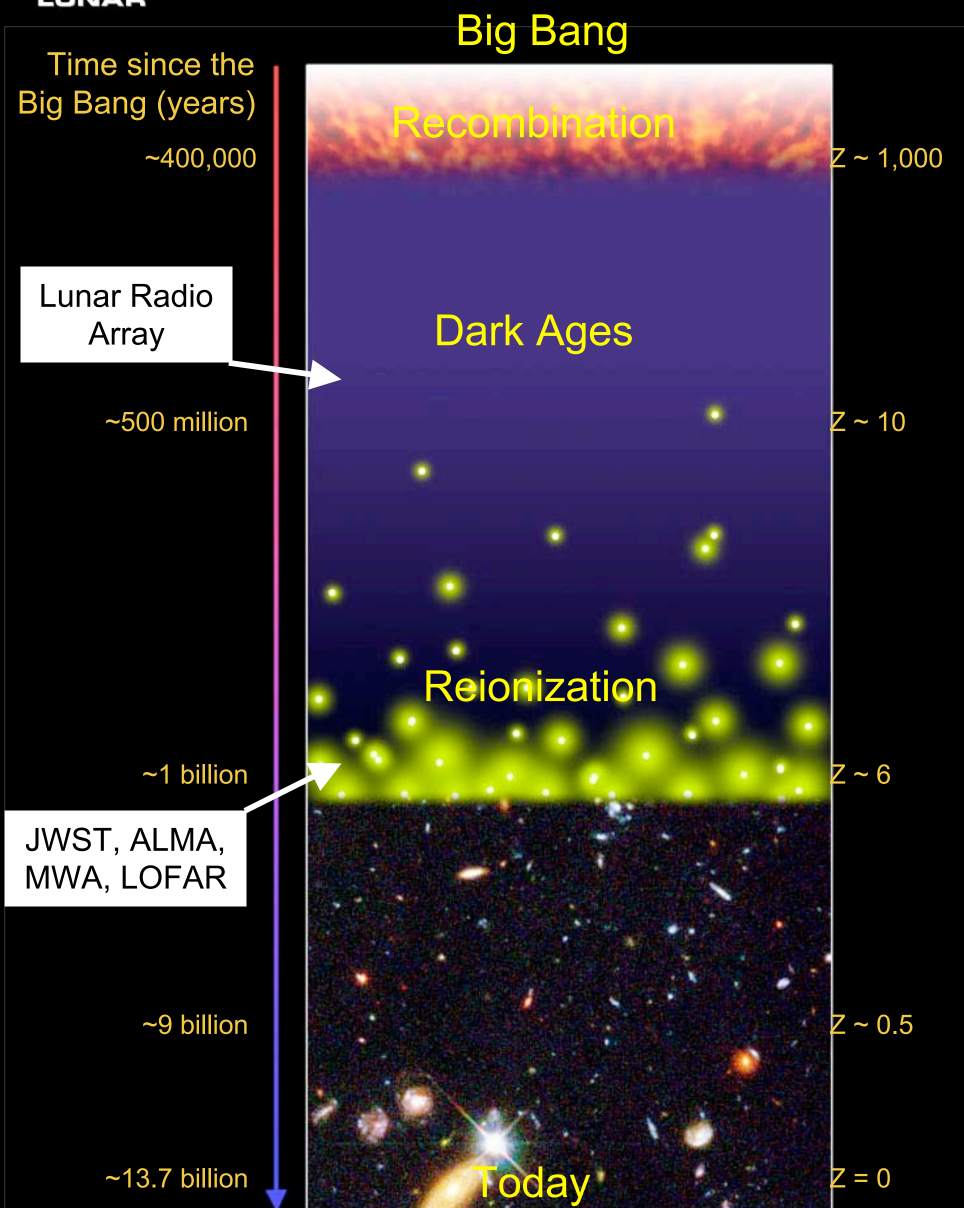


A sheet of film on the unrolling device inside the vacuum chamber.

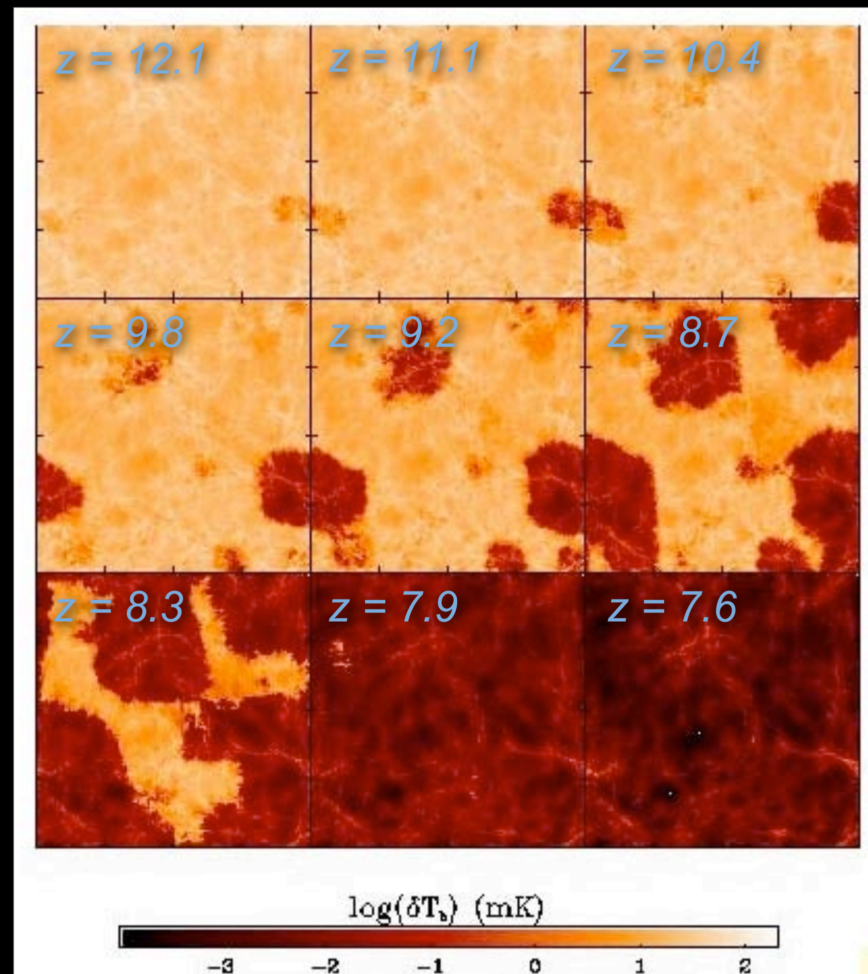
The LUNAR team inserts a sheet of film into the chamber.

See poster #41 by Kruger *et al.* entitled ***Exploration of the Dark Ages: An investigation into Kapton's suitability as a radio telescope material***

Reionization and the Dark Ages

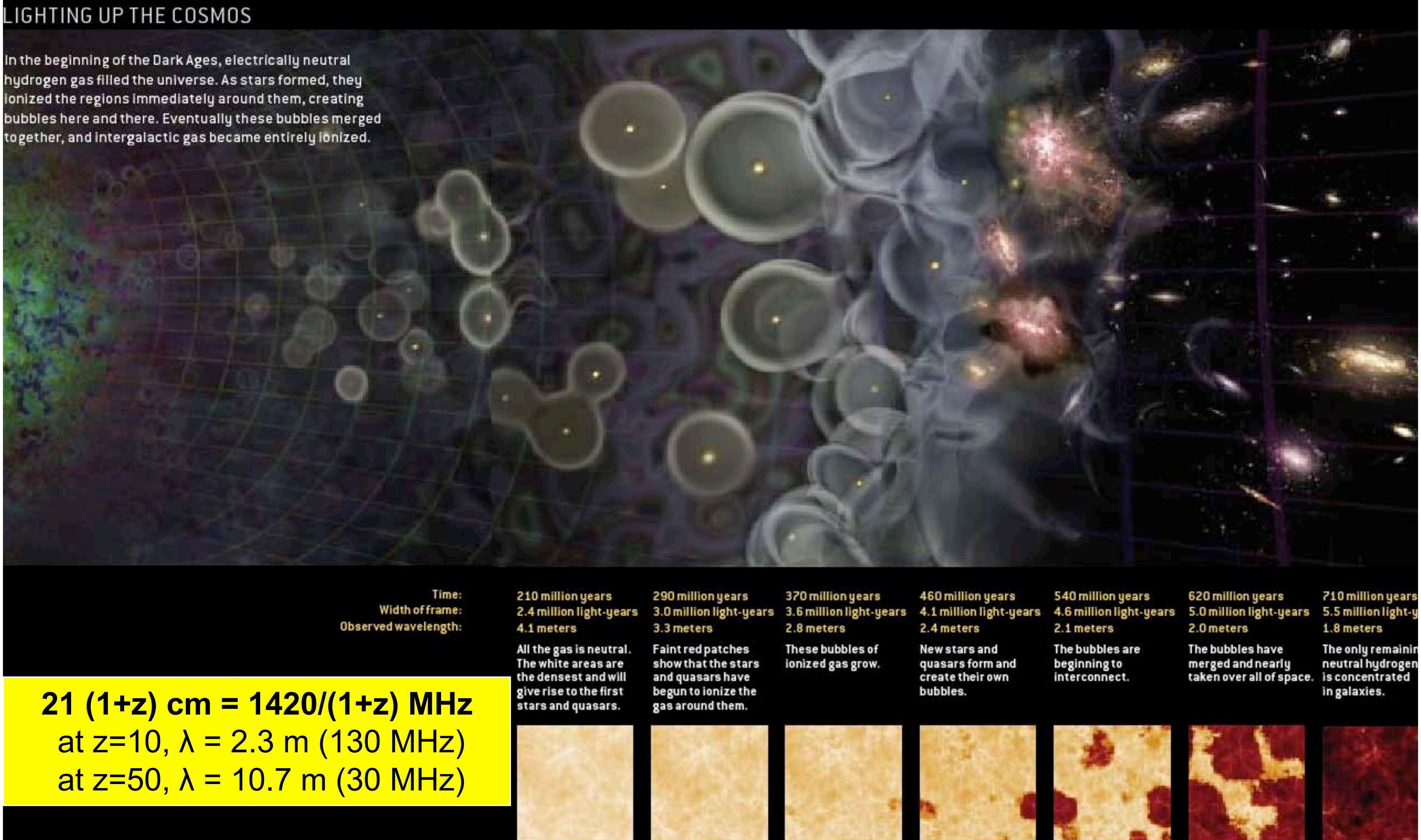


Reionization



Fluctuations are at about 10 mK

Evolution of the Universe via the Highly Redshifted 21-cm Line

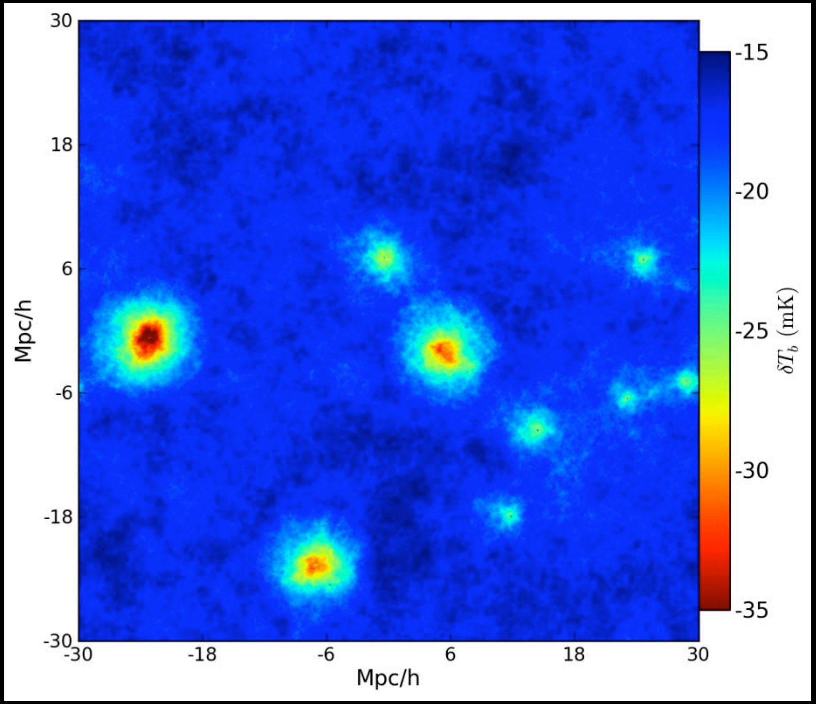


21 (1+z) cm = 1420/(1+z) MHz
at z=10, λ = 2.3 m (130 MHz)
at z=50, λ = 10.7 m (30 MHz)

Loeb, A. 2006, *Scientific American*, 295, 46.

Simulating the 21cm Signal

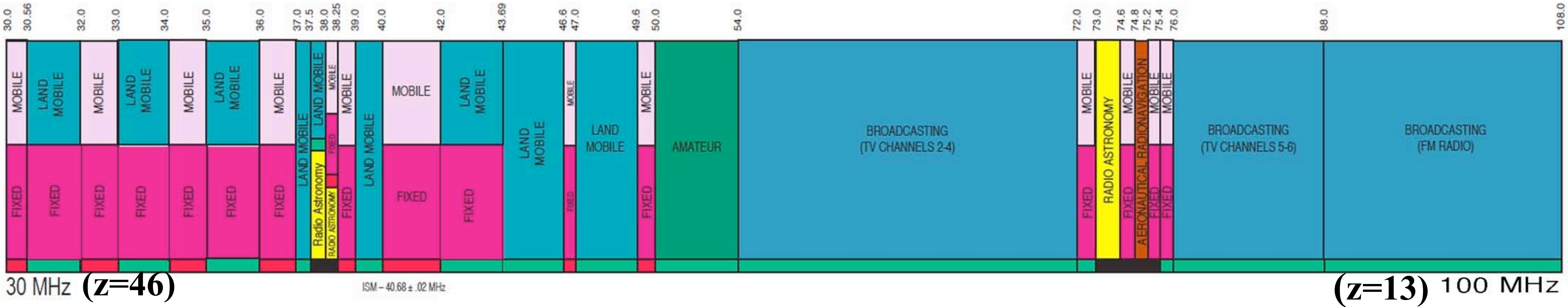
- Current focus on X-ray heating – long mean free paths mean large scale impact on HI.
- Use 21-cm as diagnostic of the earliest phases of black hole growth in the early universe.



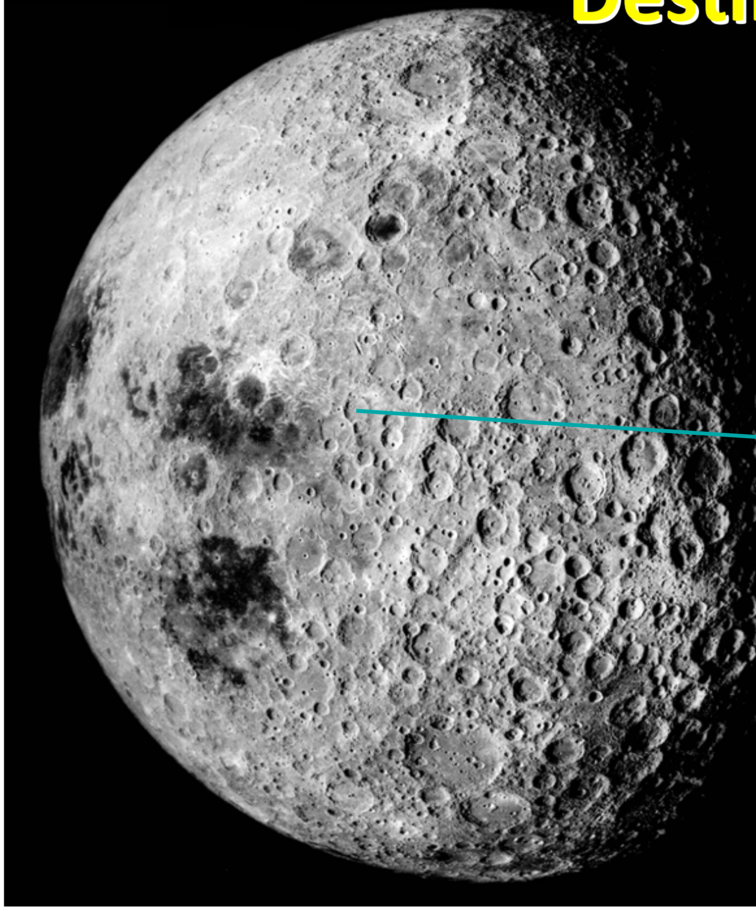
Simulated map of the HI differential brightness temperature at z = 16.

See poster #42 by Mirocha *et al.* entitled ***Cosmological Numerical Simulations of X-ray Heating During the Universe's "Dark Ages": Predictions for Observations with a Lunar Farside Radio Telescope***

Lunar Advantage: No Interference!



Destination: Moon!



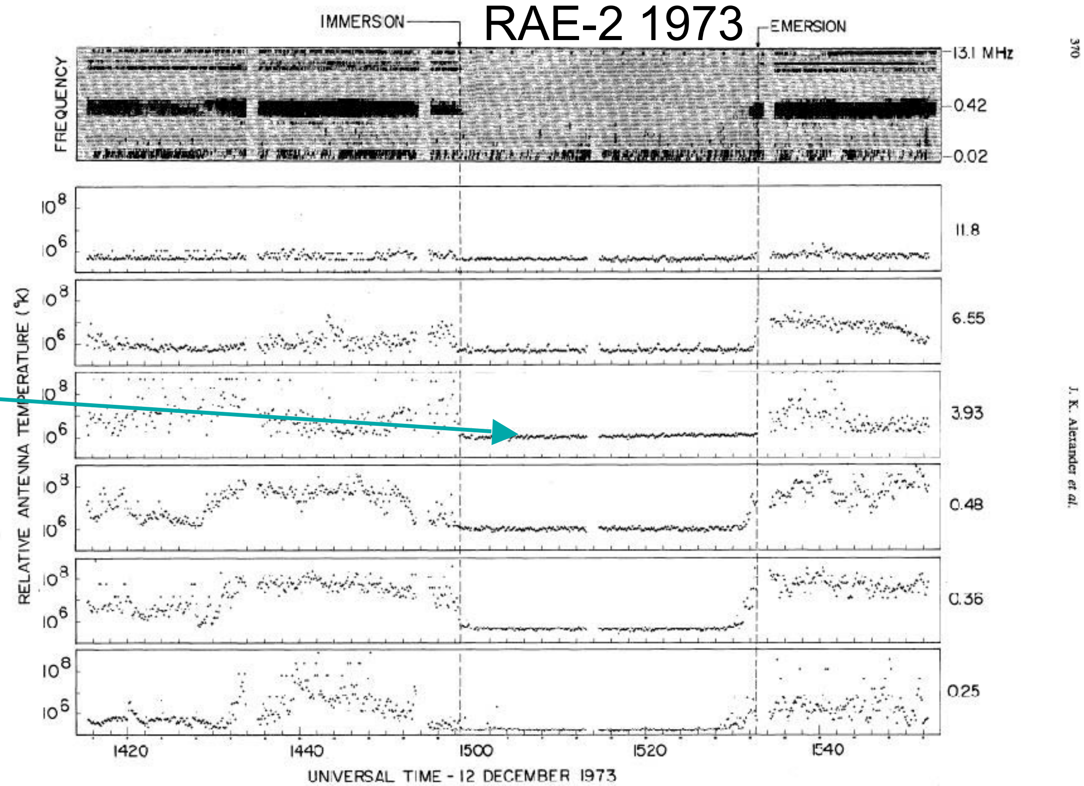
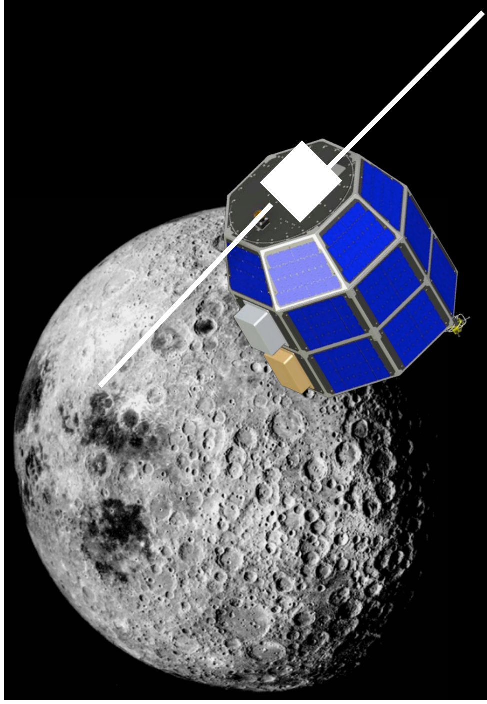


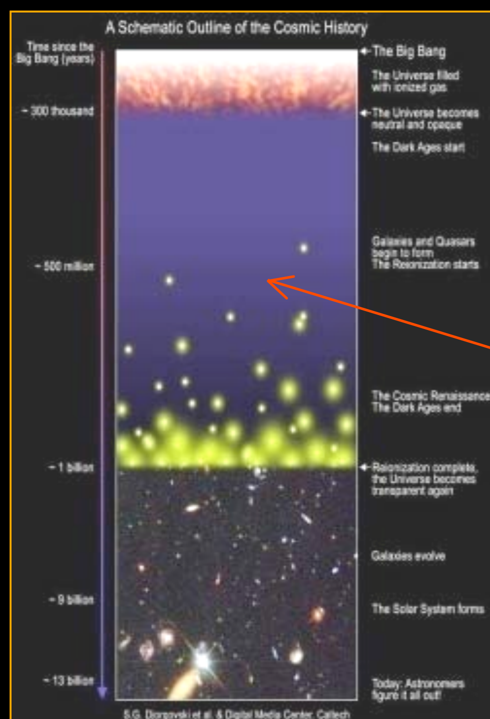
Fig. 5. Example of a lunar occultation of the Earth as observed with the upper-V burst receiver. The top frame is a computer-generated dynamic spectrum; the other plots display intensity vs. time variations at frequencies where terrestrial noise levels are often observed. The 80-s data gaps which occur every 20 m are at times when in-flight calibrations occur. The short noise pulses observed every 144 s at the highest frequencies during the occultation period are due to weak interference from the Ryle-Vonberg receiver local oscillator on occasions when both that receiver and the burst receiver are tuned to the same frequency

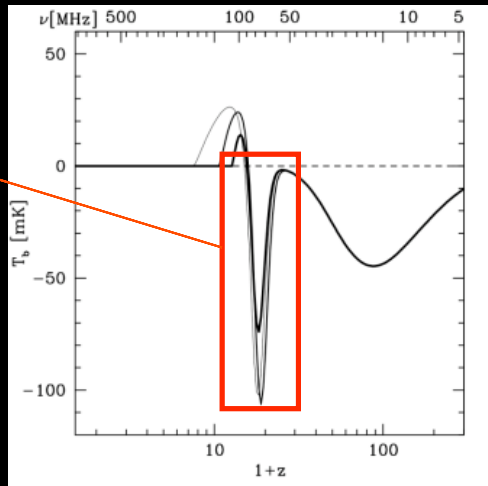
Mission Concept

Lunar Cosmology Dipole Explorer (LCoDE)

- Key Science: Detect (highly redshifted) H I signal from intergalactic medium from the time of the first stars & possibly the Dark Ages at $\nu < 100$ MHz.
- Single (dual-polarization) dipole on orbiting spacecraft.



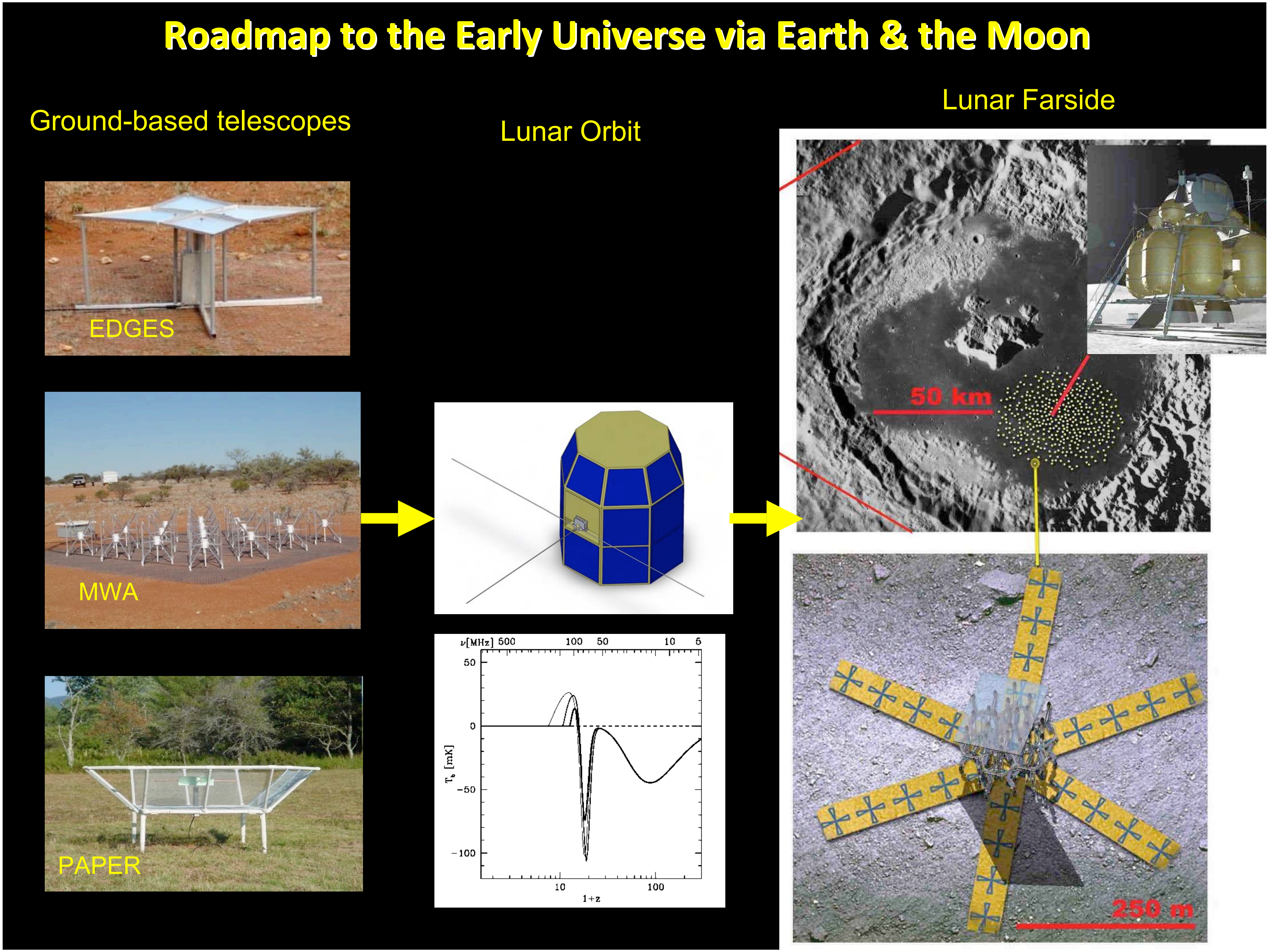




Science Package and Requirements

Lunar Cosmology Dipole

- Orbit with maximal duration behind Moon, in shielded zone.
- Single dual-polarization dipole and receiver.
- Frequency range: 20–100 MHz.
- High-speed, low-bit depth sampling.
- High Technical Readiness Level (TRL >6) components.
- <2 kg mass; <2 W power.


Roadmap to the Early Universe via Earth & the Moon
Ground-based telescopes
Lunar Orbit
Lunar Farside
EDGES
MWA
PAPER
ν[MHz] 500
100
50
10
5
50
0
−50
−100
T_b [mK]
10
100
1+z
50 km
250 m

Other Lunar-based Observatory Concepts

P.C. Chen,
Lightweight Telescopes, Inc.

Fig.15. Artist's concept of a lunar telescope with alt-alt superconductor bearings. Drawing by Alan Chen (RPI) and Heather Chen (St. Mary's College. of MD). Background courtesy of NHK TV Japan.

See posters #156 & #155

Fig.13. An OTA assembly consisting of a thin composite mirror (foreground) and a tube assembly made of sheet metal. Two support rods to hold upper stage magnets can be seen protruding from just below the middle of the tube.

P.D. Lowman,
GSFC

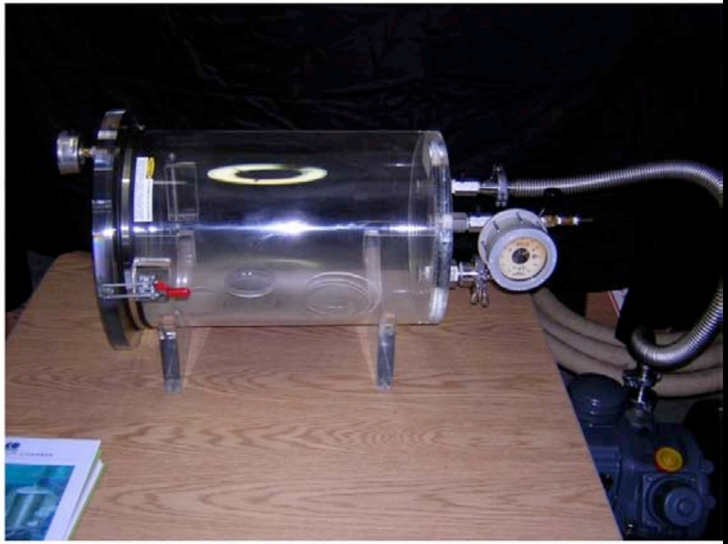


Fig. 12. Apparatus for testing long term vacuum stability of lunar cement samples. The chamber is 29 cm diameter x 46 cm long

See poster #158

LOCO
Lunar Occultation Observer

A Nuclear Astrophysics All-Sky Survey Mission

R.S. Miller (PI)
Associate Professor
UAHuntsville

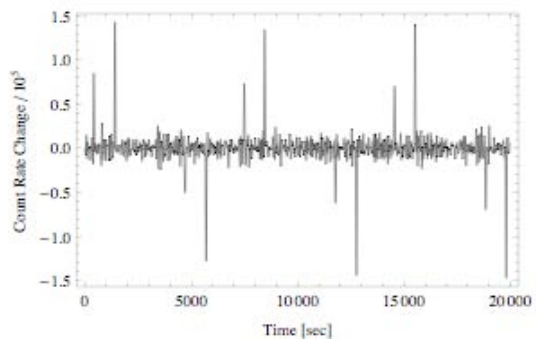
The Moon as a Unique Scientific Platform
Utilize Benefits of Lunar Environment for Science

New Imaging Paradigm
Temporal Modulation Imaging & Spectroscopy

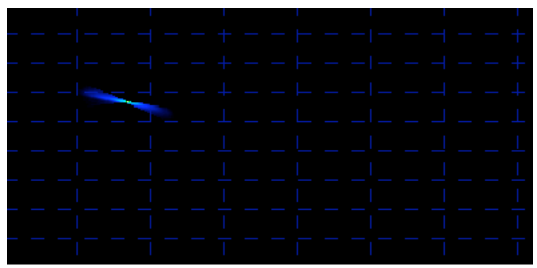
γ-Ray Survey (0.1-10 MeV)
Last Electromagnetic Regime w/o Sensitive Sky Survey

UAHuntsville
THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

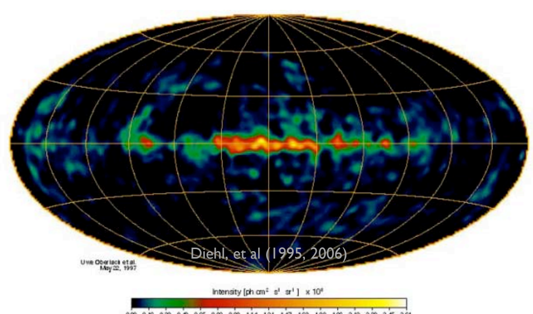
Temporal Source Modulation Due to Lunar Orbit



Deconvolution of Images From Time Series Data



Mapping of Nuclear Emissions



Point- & Extended Source Analyses w/ 10x Sensitivity of Previous Missions

- Galactic Nucleosynthesis
- Novae & Supernovae
- Black Hole Census
- Active Galactic Nuclei
- Solar Physics
- Lunar Science

Mission Profile
Explorer-Class Mission
Overview

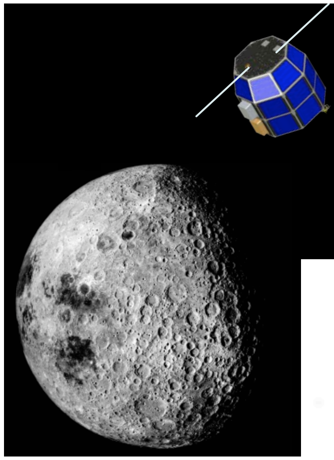
Simplified Implementation Approach

Operations Similar to Planetary Mission

No Complex Imaging Instrument Required

- Energy Range: ~0.1-10 MeV
- Spectral Resolution: <4% FWHM
- Sky Coverage: 90%
- Point Source Localization: ~0.5’
- Detector Area/Mass: ~1 m^2, <200 kg
- Lunar Orbit: 100-200 km Polar

See poster #112



LUNAR

LUNAR

For more results from LUNAR, see poster #135 by Benjamin *et al.* entitled ***Lunar University Network for Astrophysics Research (LUNAR) Team - Accomplishments from the First Year***